DDF annual report

Title of Investigation:

A Nanoscale Magnetic Sensor for Interplanetary Exploration

Principal Investigator:

Stephanie Getty (Code 541)

Initiation Year:

FY 2005

Funding Authorized for FY 2005:

$55,000

Actual or Expected Expenditure of FY 2005 Funding:

In-house: $55,000

Status of Investigation at End of FY 2005:

To be continued in FY 2006, with an additional $20,000 in FY 2006 DDF funding.

Expected Completion Date:

September 2006

Purpose of Investigation:

Measurements of magnetic fields in space usually are made with instruments that are bulky and require significant power. This work is an effort to develop a lightweight, compact, low-power device to measure magnetic fields. The device is made from a single-walled carbon-nanotube (SWCNT) structure, grown by chemical vapor deposition (CVD). It features an iron needle that is deflected in a magnetic field, as shown in Figure 1. It is known that the electronic properties of SWCNTs can be modulated by mechanical perturbation. The resistance of the device can be monitored under strain due to deflection of the iron needle in an external magnetic field. The magnetometer is freestanding and lightweight. The resulting device promises reduced power requirements, mass, and size (see Table 1), and comparable sensitivity to existing technology.

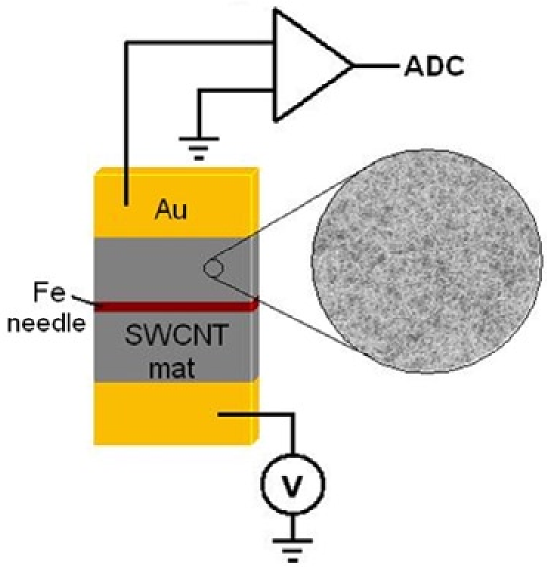

Figure 1. Nanoscale-magnetometer design features lightweight, electromechanically sensitive SWCNT mat, gold contact pads for electrical probing and mechanical support, and iron needle

	NanoMag	Fluxgate (ST5)
Max Op Temp	450°C	100°C
Sensor Dimensions	1 cm x 1 cm x 100 nm (variable)	4 x 4 x 6 cm^3
Sensor Mass	10^{-5} g	75 g
Sensor Op Power	10^{-3} - 10^{-2} mW	50 mW

Table 1. Projected specifications of the nanoscale magnetometer compare favorably to those of a technology demonstration fluxgate magnetometer flown on ST5.

Accomplishments to Date:

With FY 2005 DDF support, a Goddard Space Flight Center (GSFC) carbon nanotube CVD growth facility has been established for fabrication of both SWCNTs and multi-walled carbon nanotubes (MWCNTs). A magnetic measurement station also has been installed for magnetometer characterization, featuring a low-field, open-access electronic probe station that represents a unique capability at Goddard. Supporting laboratory facilities are under development, including a thin-film evaporator and vacuum chamber.

We have made significant advances toward fabricating a high-quality SWCNT mat for implementation as the basis of a nanostructured magnetometer. Figure 2 shows a scanning- electron micrograph of a dense, interconnected ensemble of SWCNTs grown at GSFC. The SWCNT mat is continuous across a 1-cm x 1-cm specimen and represents a significant advance in the fabrication of a nanoscale magnetometer.

Electrical characterization reveals that the SWCNT mat shown in Figure 2 is conducting hundreds of microns. Electrical probing of the specimen was accomplished by patterning a series of gold electrodes on the surface of the SWCNT ensemble, as shown in Figure 3, applying a bias voltage across the contacted SWCNT matrix with tungsten probe needles, and measuring the current response of the device.

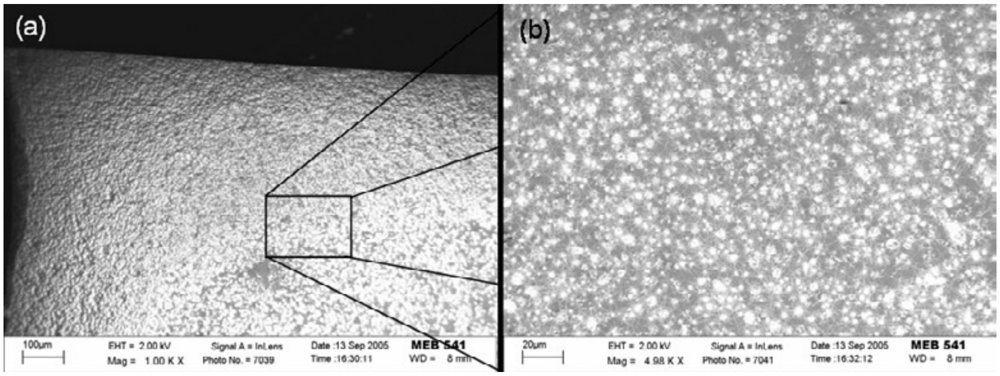

Figure 2. Scanning electron micrographs of GSFC- grown SWCNTs, shown as bright interconnecting lines at (a) low magnification to show uniformity and (b) high magnification to show detail.

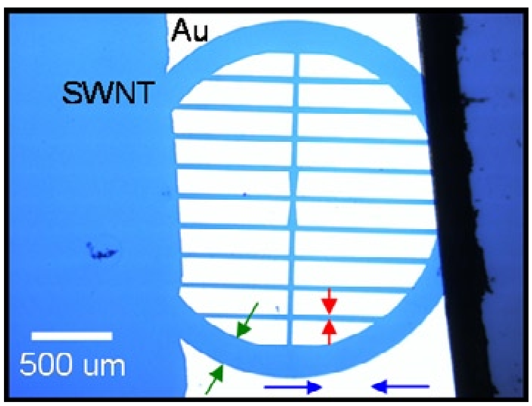

Figure 3. Optical image of gold electrode pattern on SWCNT specimen. The reflective regions are coated with gold, and SWCNTs bridge the electrodes in the dim blue regions. The arrows denote the locations of three electronic devices discussed further in the text.

Electronic transport measurements are shown in Figure 4. Current was measured as a function of voltage, and the linear slope gives conductance (1/resistance). The measured current for the SWCNT device spanning the two red arrows is shown in red in Figure 3. Here, the device length is 54 microns, and the resistance of the device is 418 kohms. The green curve was measured across the device between the green arrows in Figure 3. The device length is 249 microns, and the device resistance is 590 kohms. The blue curve is measured across the gold film and is included for contrast.

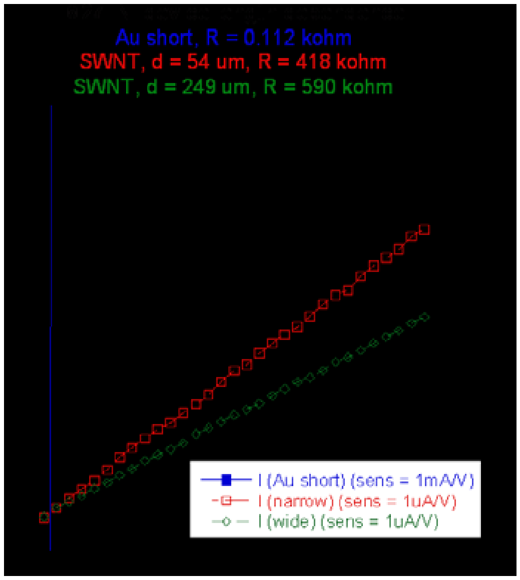

Figure 4. Current (in nA) versus voltage (in mV) in a SWCNT ensemble. The inverse of the slope gives device resistance, which is relatively insensitive to device length.

Comparison of the two SWCNT devices leads to a promising result—for a nearly five-fold increase in device length, the device resistance has only increased by 40 percent. This finding illustrates a unique advantage of nanostructured materials over conventional solids, in which a five-fold increase in device length produces a five-fold increase in device resistance. These results indicate that SWCNT devices can show little dependence on device length, making the material ideal for adaptability to a broad range of device dimensions and configurations.

Using the New Technology Reporting (NTR) system, the PI has submitted a patent disclosure entitled, "Design of a Lightweight, Low-power Magnetometer Based on a Single-walled Carbon Nanotube Mat."

Planned Future Work:

Through the investigations described above, much has been learned about the growth of SWCNTs and their as-grown electronic properties, enabling improvements to the magnetometer design. Future work includes fabricating the remaining thin-film components (electrodes and iron needle), releasing the SWCNT mat from its substrate, and testing the freestanding structure in the magnetic measurement facility.

Key Points Summary:

Project's innovative features: The nanoscale-magnetic sensor is based on a lightweight SWCNT, whose electronic properties are sensitive to bending. An iron needle is engineered into the sensor's design so that external magnetic field will apply torque to the sensor in a predictable way. The degree of sensor deflection will be proportional to applied magnetic field, and the sensor read-out is in the form of an electronic signal. The sensitivity of the magnetic sensor is expected to be higher in a SWCNT-based material than in a conventional material, such as silicon.

Potential payoff to Goddard/NASA: The development of a SWCNT-based magnetic sensor is geared toward solar-system exploration. The proposed magnetic sensor is designed to be a facet of a comprehensive study of other planets and moons, replacing an existing technology to reduce mass, power, and size requirements.

The criteria for success: A successful nanoscale magnetometer prototype will exhibit sensitivity capable of detecting magnetic fields in the nano-Tesla regime, while approaching the projected benefits in device mass, size, and power requirements shown in Table 1.

Technical risk factors: SWCNT-growth studies conducted at GSFC have shown that growth mechanics of a single nanotube can differ greatly from those of an ensemble of nanotubes. Interactions during growth prohibit the final morphology predicted in the early stages of this project. Changes have accordingly been made to the magnetometer design, and the final prototype will demonstrate superior performance.

A chromium film was designated to be the sacrificial release layer to free the SWCNT mat from its substrate. Preliminary studies have shown that chromium may interfere with the CVD growth, and a chromium-free strategy may need to be used. Further studies are being pursued. Ideas for eliminating the need for chromium may focus on growing the SWCNTs across a void in the substrate and subsequently attaching the iron needle.